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ABSTRACT

This paper describes a Personal Intelligent Mentor (PIM) that facilitates metacognitive development in the domain of solving logic word puzzles. Metacognition is an important aspect for critical thinking skills. High school students must develop logical and critical thinking abilities as a prerequisite for higher-level math and computer programming classes. There is substantial interest at present in the development and use of software agents. They are being deployed in large and increasing numbers to assist users in finding and managing information. This research focuses on how intelligent agents can help students to improve their problem solving skills. The paper first motivates the utility and need for agents for education. Using this motivation as a guide, requirements are derived for the formation of a PIM as a cognitive tool. The paper then describes possible tasks for the Personal Intelligent Mentor and discusses how the PIM will interact with other agents, its environment, and users to improve its capabilities. (Contains 19 references.) (Author/AEF)

A Personal Intelligent Mentor for Promoting Metacognition in Solving Logic Word Puzzles

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Abstract: Metacognition is an important aspect for critical thinking skills. This paper describes a Personal Intelligent Mentor (PIM) that facilitates metacognitive development in the domain of solving logic word puzzles. There is substantial interest at present in the development and use of software agents. They are being deployed in large and increasing numbers to assist users in finding and managing information. Our research focuses on how intelligent agents can help students to improve their problem solving skills. The paper first motivates the utility and the need for agents for education. Using this motivation as a guide, we derive requirements for the formation of a PIM as a cognitive tool. We then describe possible tasks for the Personal Intelligent Mentor and finally we discuss how the PIM will interact with other agents, its environment and user to improve its capabilities.

1 Introduction

The focus of this research is to promote metacognition. Schoenfeld (1987) describes three categories of metacognition: 1) knowledge of one's thought processes; 2) control or self-regulation; 3) beliefs or intuitions. For the purposes of this research, we will focus on the first and second categories: that metacognition incorporates knowledge and monitoring of one's thought processes. Information processing models of cognition (e.g., Pressley & McCormick, 1995) suggest the primary importance of metacognitive skills, particularly as metacognitive ability is a feature of expert problem solvers (Glaser & Chi, 1988). Whereas novices tend to focus on surface features of a problem, experts tend to better organize and represent the information and use more metacognitive skills. Although a metacognitive state may hinder intuitive ability (Baylor, in press), it is beneficial for other reasoning processes.

One particularly salient reasoning process that depends on metacognitive skills is logical reasoning. High school students must develop logical and critical thinking abilities as a prerequisite for higher-level math (e.g. advanced algebra, trigonometry, calculus), science (e.g. chemistry, physics, applied biology), and computer programming classes. Part of the problem with a traditional approach to teaching logic is that logic, by its very nature, is abstract. When metacognitive reasoning of logical reasoning is considered, it is very abstract! We chose to research high school students' metacognitive reasoning with logic word puzzles (see example in Appendix A) because they are concrete, well-defined, and are more motivational for the students than simply answering questions about logic.

The primary goal of this research is to give high school students practice in thinking logically and developing problem-solving strategies through the process of solving logic word puzzles

using an intelligent agent (specifically, a Personal Intelligent Mentor (PIM)) as a cognitive tool.

2 The role of artificial intelligence

In general, an intelligent agent can be defined as a software program that performs some tasks in an environment with autonomous processing capabilities, so "any property of an agent must therefore be defined in terms of the task and the environment in which the task is to be performed" (Goodwin, 1993). From an educational vantage point, a better description might be that intelligent agents are computer programs that simulate a human relationship by doing something that another person could otherwise do for you (Seiker, 1994, p.92).

The goal of our research is that as a result of solving the logic puzzles interactively with the intelligent agent (i.e., Personal Intelligent Mentor), students will improve their semantic understanding of logic and their logical problem-solving skills. Throughout the problem-solving process, the PIM will facilitate metacognition and promote mindfulness while the student is problem-solving.

In considering the use of intelligent systems for education, there are generally two camps (Lajoie & Derry, 1993): 1) those who promote using the system as a cognitive tool to stimulate the student to monitor and diagnose performance; and, 2) those who promote using the model building approach to use the system as an intelligent tutor. In our approach, the agent will function more as an intelligent cognitive tool than as an intelligent tutor or assistant.

3 The Personal Intelligent Mentor (PIM) as a cognitive tool

Cognitive tools (e.g. Lajoie & Derry, 1993) are mental and computational devices that support, guide, and extend the thinking processes of their students (Derry, 1990). The agent in this project will serve a similar function. From a learning theory perspective, the concept of distributed cognitions (Salomon, 1993b) readily applies to intelligent agents since they could be used to serve as extensions of a person's intellectual capacity. Similarly, Vygotsky (1962) defines a person's zone of proximal development to be the limit for his/her ability to imitate processes demonstrated by others. By extending the cognitive capabilities of the person, intelligent agents could serve to thus augment a person's zone of proximal development.

For an intelligent agent to facilitate the learning process, it is necessary for the student to actively use the agent as a cognitive tool rather than passively letting the agent retrieve information. In this way the intelligent agent provides an environment where the learner must think harder and more deeply about the content, using the agent as a natural cognitive extension. This research allows for intelligent agents to support an individual's metacognitive processes with the agents serving as a technological "reciprocal teacher" (e.g. Palinscar & Brown, 1984), prompting the individual to engage in analysis of his/her own cognitive processes. This tool serves to encourage the individual to assess what cognitive strategies are being used, similar to Salomon's pedagogic computer program, the Writing Partner (Salomon, 1993a), which asks the learner intelligent questions through the writing process.

Aside from serving as a cognitive tool, an additional feature is that the intelligent agents can

be developed to adapt behavior based on the student's history of performances. In this way, the agents could analyze the student's approach to a task, build a database of past activities, and provide suggestions of better strategies. In effect, the agents learn the way that the student learns. In this manner, the agents could infer expected behavior and advise the student accordingly. A critical issue in terms of educational value is in moderating between the agent taking over thinking for the student with the agent training the student to think more effectively. Salomon (1993a) refers to this as the difference between the effects "of" and "with" technology, with effects "with" technology being more desirable. We address this by providing a monitor serving the primary purpose of determining the correct amount of feedback.

Before we define the properties of the Personal Intelligent Mentor (PIM), we will describe its capabilities and environment, since the properties of an agent depend on its environment and task. A task is a description of what the agent is supposed to achieve in the environment. The following section describes possible tasks for the Personal Intelligent Mentor based on educational principles.

4 Possible tasks for Personal Intelligent Mentor (PIM)

4.1 Serve as a pedagogical expert

The PIM will monitor and evaluate the timing and implementation of teaching interventions (e.g. help, feedback). McArthur, Lewis and Bishay (1993) state that the pedagogical component of intelligent systems receives relatively little mention with current systems demonstrating little pedagogical expertise. As they suggest, most intelligent tutoring systems are constrained to a single method of teaching and learning, while truly expert human tutors can adopt different methods. Drawing from human research on expert tutoring, the PIM will be able to mentor flexibly, as a human mentor would.

In terms of developing a relationship with the student, the PIM will obviously need to be trustworthy, honest, and cooperative while providing feedback. An important part of this feature is that the PIM will resemble a human tutor in terms of motivational qualities. As Lepper & Chabay (1987) propose, motivational components are as important as cognitive components for an intelligent tutor. Taking it one step further, they propose that bringing empathy to computer tutors is conducive to learning. The PIM is developed with these considerations in mind.

The relationship of the PIM to the student can be described as a cognitive apprenticeship, where the student improves his/her performance while working with the more expert performer: the Personal Intelligent Mentor. In support of this feature, Collins & Brown (1987) suggest that students may learn best in environments that include agents which can intensively model and coach formative skills. Under our approach, as the student gains expertise, the agent would fade and allow for more student initiative.

4.2 Evaluate student's progress in terms of logical reasoning

While there is flexibility for accommodating different problem-solving approaches and preferences, the PIM will apply basic rules of logic to evaluate the student's logical reasoning.

For example, this task of the PIM would be to identify typical errors in logical reasoning, such as "modus tollens," where the student wrongly infers that "if A then B "and "B is false" then "A is false".

The PIM will also provide a detailed error analysis of student progress.

4.3 Assess student progress

The PIM will determine student progress in the problem, in terms of correctly-eliminated logically contradicted cases, and a clue by clue analysis.

4.4 Promote reflection and mindfulness

COACH is an intelligent agent system by Seiker (1994) that records user experience to create personalized user help for LISP with an adaptive interactive help system. As Seiker describes, (p. 92) "Just as a football coach will stand on the sidelines and encourage, cajole or reprimand, so COACH is an advisory system that does not interfere with the user's actions but comments opportunistically to help the user along." Like COACH, this PIM will serve as an advisory-style agent that builds a user relationship and has explicit goal of educating the individual (Seiker, p. 93). Similarly, the PIM will draw from an adaptive user model that selects appropriate advice.

4.5 Demonstrate expert performance

At any time in the session, the student may request the PIM to demonstrate the reasoning involved in the solution of a similar problem. This may serve as feedback for an incorrect answer and/or to "coach" the student as to why a particular strategy should be selected.

4.6 Provide flexible feedback

The feedback will be supplied in different chunks: from highly detailed to more global. One of the primary goals for the feedback is to facilitate student metacognition and reflection, and feedback addresses this goal in three ways. First, the PIM will be able to show the student a "tree" of his/her problem-solving process and show errors in performance trends. This is conducive to developing student reflection on his/her performance (Collins & Brown, 1987). Second, at appropriate times, the PIM will ask the student to explain why s/he chose a particular response, to get the student to analyze his/her problem-solving behavior. Third, the PIM will provide appropriate follow-up practice.

One final consideration in terms of feedback is that the PIM will not provide too many insights and thereby annoy the student. To address this issue, part of the pedagogical task includes the monitoring of the timing and implementation of the advisements. The principle of minimal help will be the default. Also, the student will be able to select a feedback option depending on the amount of structure s/he desires when problem-solving. If s/he desires maximum interaction and feedback, the agents will gradually reduce assistance over time.

4.7 Visually assist with problem solving

Feedback will also facilitate learning by providing multiple representations of the information.

It is hypothesized that learning is improved due to the formulating of multiple representations by the person (e.g. Lehrer, Erickson, & Connell, 1994). As a way of managing detail, Adelson & Soloway (1988) describe how expert software designers make mental "notes" to themselves about things to remember in the design process. Goel & Pirolli (1992) claim that interim design ideas or solutions are generated, retained, and incrementally developed -- they are rarely forgotten or discarded. Since it is believed that these mental "notes" serve as a mental representation and contribute to the learning process, the student will be provided with a computer-based notepad to maintain his/her ideas, strategies, and mental notes.

Additionally, as mentioned previously, the PIM will be able to show the student a "tree" of his/her problem-solving process to visually show errors in performance trends.

4.8 Monitor student generation of a logic problem

A special feature of our system is the opportunity for the student to create his/her own personal logical word puzzle. In this component of the system, the PIM guides the student in the creating and testing process. This serves as a generative learning activity that is beneficial because it forces the student to consciously relate the logic problem-solving strategies to information he/she knows is true, thereby incorporating personal knowledge while also problem-creating.

4.9 Management of student control

The setting for the logic problem-solving is constructivist because it allows the student to problem-solve in his/her preferred manner, and to discover truths for his/herself. In this constructivist environment, the agent serves as a "guide." For example, when the student seems to be aimlessly trying different strategies (i.e., "thrashing"), the agent will intervene. In one way there is program control: the program will select the next problem for the student based on what s/he "needs" most. This feature follows more of a traditional ITS approach. On the opposite end of the continuum is the component of the program which allows the student to create his/her own logic problem. This feature follows more of an interactive learning environment approach. Overall, it is a mixed approach: the student is in an interactive learning environment supplemented with locally intelligent agents.

5 Properties of the Personal Intelligent Mentor

The environment in which PIM operates is dynamically changing. Based on the task and the environment, there are two main properties of the PIM: agency and intelligence.

5.1 Agency

Agency defines the basic characteristics of the PIM with the following descriptive facets:

Autonomy. An important characteristic of agency is autonomy, i.e., PIM is an autonomous software entity. It can take initiative and operate in a dynamic environment without interacting with a user. This is one of the major features that distinguishes an agent from other software programs. The PIM also has some degree of control over its own actions.

Social Ability. The PIM can interact with other agents. The agent might cooperate with others and then collectively gather the information to improve its action-goal.

Adaptability. The PIM has an ability to change its behavior to be able to reach its goal despite environmental changes.

Reactivity. The PIM responds to changes in its environment, and an agent is reactive if it is able to respond in a timely manner to such changes.

Communication Ability. Explicit communication is needed among agents to enable them to cooperate. An agent typically communicates with others via a high-level communication protocol.

5.2 Intelligence

Intelligence introduces a stronger notion of agency. It gives an agent the ability to learn or understand from experience and make decisions in new situations without interacting with a user.

6 Personal Intelligent Mentor as observer

A PIM needs models of other agents, its user and the environment to construct possible future scenarios that it can then use to guide its actions (to give better support to the student). For example, if the environment is the school, there is a library, computers, teachers and students. If a teacher cannot solve a problem or needs to learn something to teach the students, s/he can go to the library and check some books out or ask his/her colleagues. In this way s/he learns which books are available in the environment or which teachers have more information on logic. It seems somewhat complicated, but today information is distributed and changing dynamically. Consequently, a teacher may need to update his/her knowledge, or search for some information to obtain a better strategy to solve the logic problem. If only one agent is used, it is a more static system.

6.1 User Modeling

PIM can construct a model of its user by tracking and monitoring its observable actions. We call this passive observation.

6.2 Environment modeling

Acting upon its environment and receiving information via percepts provided by the environment, a PIM creates a model of the environment in the form of an internal map. A utility function is then used to rank states of the environment to which the PIM's actions will lead. Feedback from the environment makes the PIM more independent and can play an important role when the PIM is making decisions autonomously.

6.3 Agent modeling

Proactively an agent, via ASK-TELL or REQUEST-RESPONSE protocols, may acquire and share other agents' knowledge and use this information to construct its model. How should

PIM acquire the information it needs to construct a model of other agents? This has, we believe, a simple and elegant answer: the agent should presume that unknown agents are like itself, and it should choose to represent them as it does itself. As it learns more about them it only has to encode any differences that it discovers. This can make the resultant representation concise and efficient.

7 Conclusion

The primary goal of this research is to give high school students practice in thinking logically and developing problem-solving strategies through the process of solving logic word puzzles using an intelligent agent (specifically, a Personal Intelligent Mentor (PIM)) as a cognitive tool. We have described the basic requirements of a PIM. Our future work will include implementation of PIM and investigation of a PIM society.

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Appendix A

Sample of an easy logic word puzzle:

Problem

Mark loves animals. He has four pets: a newt, a Siamese cat, a Golden Retriever puppy, and a Piranha (fish). Mark refers to his pets as Johnny, Rusty, Scraggly, and Prickly.

Clues:

1) Johnny is EITHER the newt OR the Siamese cat.

2) Rusty is NOT the cat and is NOT the newt.

3) IF Rusty is the puppy THEN Prickly is the cat, ELSE Prickly is the newt.

4) Both Prickly and Scraggly are NOT the piranha .

5) Prickly is NOT the Golden Retriever.

6) Scraggly is NOT the Siamese cat.

What is the name of each of Mark's pet animals?

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